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Citation: *AIP Conf. Proc.* **819**, 599 (2006); doi: 10.1063/1.2187936

View online: <http://dx.doi.org/10.1063/1.2187936>

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Multichannel R-matrix Analysis of CNO Cycle Reactions

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Abstract. The CNO cycle is the main process for hydrogen burning in stars somewhat larger than the Sun. The reaction cross sections at Gamow energies are typically in the femto to pico-barn range and are consequently very difficult to measure experimentally. The CNO reaction rates are based on extrapolations of experimental data from higher energies. We have developed a multi-channel R-matrix code to provide a new tool for fitting experimental data and making extrapolations to lower energies in all reaction and scattering channels. This approach does not only allow for a more reliable extrapolation, it also provides insight and guidance for the next generation of low energy experiments.

Keywords: R-matrix, CNO Cycle

PACS: 25.40.Lw Radiative capture - 26.20.+f Hydrostatic stellar nucleosynthesis

THE $^{14}\text{N}(\text{p},\gamma)^{15}\text{O}$ REACTION

The $^{14}\text{N}(\text{p},\gamma)^{15}\text{O}$ reaction determines the overall rate of the CNO cycle and hence energy production in stars larger than 1.5 solar masses. It also plays a role in determining the age of globular clusters. Recently this reaction was measured at LUNA (Laboratory for Underground Nuclear Astrophysics, Gran Sasso, Italy,) [1] and LENA (Laboratory for Experimental Nuclear Astrophysics, North Carolina, USA) [2]. In this analysis the $^{14}\text{N}(\text{p},\text{p})^{14}\text{N}$ scattering channel has also been included [3]. Preliminary fits, which include the data of [4], are shown in Figure 1.

Our preliminary results are in reasonable agreement with results from the literature (see Table 1). Further analysis is underway to determine the effect of the elastic scat-

FIGURE 1. Preliminary R-matrix fits for γ transitions to the ground, 6.79 MeV and 6.18 MeV states.

TABLE 1. Summary of $S(0)$ values (in units of keV b)

Transition to (MeV)	Ref. [4]	Ref. [5]	Ref. [1]	Ref. [2]	Present
0.00	1.55 ± 0.34	$0.08^{+0.13}_{-0.06}$	0.25 ± 0.06	0.49 ± 0.08	0.14
6.18	0.14 ± 0.05	$0.06^{+0.11}_{-0.02}$	$0.06^{+0.11}_{-0.02}$ *	0.04 ± 0.01	0.20
6.79	1.41 ± 0.02	1.63 ± 0.17	1.35 ± 0.05	1.15 ± 0.05	1.17

* Taken from Ref. [5]

tering channel on the low energy extrapolation. Measurements of the subthreshold state lifetime [6] may offer some additional constraint on the $S(0)$ in the ground state transition. S_{total} measurements may constrain the $S(0)$ further still.

THE $^{15}\text{N}(\text{p},\gamma)^{16}\text{O}$ AND $^{15}\text{N}(\text{p},\alpha)^{12}\text{C}$ REACTIONS

The branching between the first and second CNO cycles is defined by the $^{15}\text{N}(\text{p},\gamma)^{16}\text{O}$ [7] and $^{15}\text{N}(\text{p},\alpha)^{12}\text{C}$ [8, 9, 10] reactions. We are reanalysing these reactions incorporating the $^{12}\text{C}(\alpha,\alpha)^{12}\text{C}$ [11] channel. Figure 2 shows preliminary fits.

FIGURE 2. Preliminary R-matrix fits for $^{15}\text{N}(\text{p},\gamma)^{16}\text{O}$, $^{15}\text{N}(\text{p},\alpha)^{12}\text{C}$ and $^{12}\text{C}(\alpha,\alpha)^{12}\text{C}$

Currently only data up to the proton threshold (5 MeV) has been considered in the $^{12}\text{C}(\alpha,\alpha)^{12}\text{C}$ channel, though higher energy data is available. As the α exit channels share R-matrix parameters, the reliability of the extrapolations in the $^{15}\text{N}(\text{p},\alpha)^{12}\text{C}$ should be improved. This in turn should improve the reliability in the γ exit channel.

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